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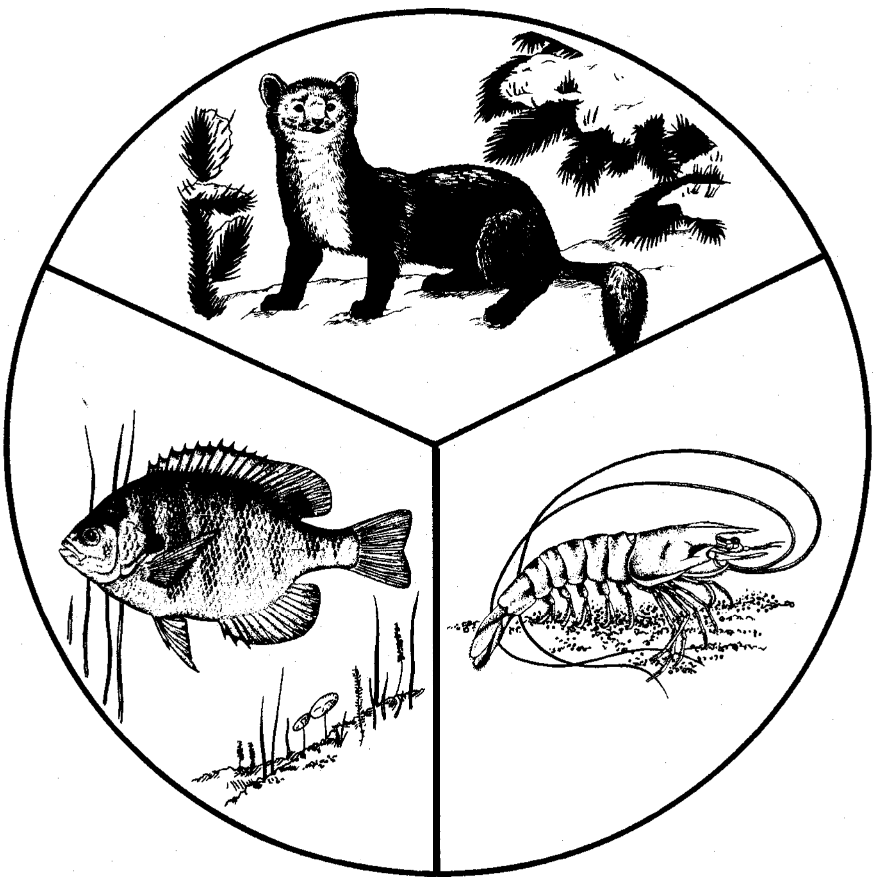
HABITAT SUITABILITY INDEX MODELS: APPENDIX A. GUIDELINES FOR RIVERINE AND LACUSTRINE APPLICATIONS OF FISH HSI MODELS WITH THE HABITAT EVALUATION PROCEDURES



Fish and Wildlife Service

S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of informatlon on national fish and wildlife resources, particularly in respect to environmental impact assessment.

- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.

- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staffs, who provide a link to problems at theoperating level; and staffs at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

This appendix is designed to be used by the Division of Ecological Services in conjunction with the Habitat Evaluation Procedures.

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HABITAT SUITABILITY INDEX MODELS: APPENDIX A. GUIDELINES FOR RIVERINE AND LACUSTRINE APPLICATIONS OF FISH HSI MODELS WITH THE HABITAT EVALUATION PROCEDURES

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PREFACE

This appendix was developed in response to requests to provide guidance in the field application of the Habitat Suitability Index (HSI) models presented in this series. Many of these models are based on a large number of suitability index graphs and are designed as a first step in developing research hypotheses. They are not especially suitable for quick assessments of fish habitat. This appendix provides some general guidelines on how the models, based on suitability index graphs, can be used to develop a model to meet the specific planning objectives of a HEP application. Methods for predicting future values of selected aquatic habitat variables are reviewed.

The recommendations and techniques described in this appendix are based on the assumption that users of the Habitat Evaluation Procedures will be interested primarily in developing a habitat rating, based on a single site visit, that characterizes the habitat with a single number. Users who expect to deal with the development of instream flow recommendations, which may require a more dynamic representation of aquatic systems, may wish to examine the summary of instream flow methods developed by Wesche and Rechard (1980).[1]

The U.S. Fish and Wildlife Service encourages users of this appendix and the various Habitat Suitability Index models to convey comments and suggestions that might help us increase the utility and effectivenss of the habitat-based approach to planning. Please send comments to:

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[1]Wesche, T. A., and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Eisenhower Consortium for Western Environmental Forestry Research. Bulletin 9. U.S. Government Printing Office, Publication Number 1980-0-679-417/509. 122 pp.

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APPENDIX A. GUIDELINES FOR RIVERINE AND LACUSTRINE APPLICATIONS OF FISH HSI MODELS WITH THE HABITAT EVALUATION PROCEDURES

PURPOSE

Use of the Habitat Evaluation Procedures (HEP; U.S. Fish and Wildlife Service 1980a) requires a numerical rating (Habitat Suitability Index) of habitat under pre- and post-project conditions. The Habitat Suitability Index (HSI) models, published and referenced in this series, present a broad spectrum of approaches to describing habitat that may be useful in providing this numerical description. The models have varying levels of precision, generality, and realism and can be adapted to a variety of planning uses.

Development and use of HSI models requires a clear understanding of the habitat requirements of the species being evaluated, the characteristics of different types of HSI models, and the objectives of the study. The models published in this series provide a basic understanding of species habitat requirements. This appendix discusses the characteristics of different types of HSI models and describes when and how to use the different model types in order to complete six of the tasks that are part of a HEP application. These tasks, and the related section in the Habitat Evaluation Procedures (U.S. Fish and Wildlife Service 1980a), are as follows: (1) define the study area boundaries (Section 3.1); (2) develop aquatic guilds (Section 3.3B); (3) calculate the total area of available habitat (Section 4.1); (4) acquire HSI models (Section 4.2B); (5) determine the HSI for available habitat (Section 4.2C); and (6) predict future HSI's (Section 5.2C).

Completion of the first three tasks (defining study area boundaries, developing aquatic guilds, and calculating total area of available habitat) is an activity normally completed prior to collection or analysis of extensive field data and is described below under "Prefield Activities." Completion of the last three tasks is often more time consuming and involves a close examination of available models and information on habitat requirements, as well as the planning and completion of data collection in relationship to project goals. Completion of each of these last three tasks is described separately.

PREFIELD ACTIVITIES

The boundaries of the study area should include sites where actual physical impacts will occur and contiguous areas that are biologically linked to the site of physical impact where secondary changes are anticipated (U.S. Fish and Wildlife Service 1980a). Determination of this linkage requires an understanding of the life history and habitat requirements of each evaluation species. This information is available in the Habitat Use Information section and in publications listed in the References Cited section of the Habitat Suitability Index models in this series.

One of the methods described in U.S. Fish and Wildlife Service (1980a) for broadening the ecological perspective of a HEP assessment is to use species that represent groups (guilds) of species that utilize a common environmental resource. Classification of all study area species into guilds often will be a useful step prior to the selection of evaluation species. The Habitat Use Information and References Cited sections of the individual species HSI models in this series provide the information necessary to classify species into aquatic guilds. Figure A-l is an example of a guild descriptor matrix that summarizes habitat use information for selected species. Use of the matrix in Figure A-l shows that bluegill, for example, could be selected as representative of a group of fishes that utilize both warmwater temperatures and backwaters. The guilds developed from this matrix can be based on two or more column descriptors (e.g., coldwater and rocky substrate), rather than a single major category, such as temperature. The guilds selected will depend on the descriptors necessary to meet the objectives of the HEP application. Guild descriptors can be based on tolerances of, or responses to, a particular habitat alteration (e.g., turbidity) or on specific requirements for completing the life cycle. Figure A-2 is provided as a worksheet to display the habitat requirements of additional species of interest.

Available habitat is defined as the surface area capable of providing direct life support for an evaluation species (U.S. Fish and Wildlife Service 1981). Determination of the total area of available habitat is necessary for the calculation of species Habitat Units and must be done for each evaluation species for every set of present or future conditions analyzed with HEP. This determination does not require a precise model of the species habitat requirements but does require criteria for classifying habitat as "capable" or "not capable" of providing direct support. For example, if lacustrine habitat does not provide direct support for any life stage of a selected species, then lacustrine areas should be excluded from calculations of area of available habitat for that particular species. The Model Applicability and Habitat Use Information sections of the HSI models in this series describe the type of habitat normally inhabitated by the evaluation species and may be used to identify parts of the study area that qualify as available habitat.

ACQUIRING AN HSI MODEL

An HSI is a unitless number bounded by 0 and 1, where 0 indicates unsuitable habitat and 1 indicates optimum habitat (U.S. Fish and Wildlife Service 1980a). The Habitat Evaluation Procedures can be used with any method of HSI determination, as long as the method is clearly described. The recommended method of determining this index is with an HSI model that provides either a verbal or mathematical comparison of the habitat being evaluated to optimum habitat for a particular evaluation species (U.S. Fish and Wildlife Service 1981). The HSI models in this series can be used as presented or modified or

	Riverine						Lacustrine																						
	Habitat			Stream size			Habitat					Cover					Temperature			Spawning[b]							Turbidity tolerance		
							Near-shore		Open-water																				
Species[c]	Riffles, runs	Pools, eddies	Backwaters, bayous, oxbow lakes	Small (< 5 m); order: 1-3	Medium (5-30 m); order: 2-6	Large (> 30 m); order: 5+	Shallow (< 5 m)	Deep (> 5 m)	Surface (< 5 m)	Mid-water (5- 5 m)	Deep (> 5 m)	Rocky substrate	Aquatic vegetation	Cut-banks	Logs, brush, debris piles	No special cover needs	Cold (< 20°C)	Cool (20-28°C)	Warm (> 28°C)	Free-drifting eggs, no substrate req.	Eggs deposited in or on rocky substrates; current required	Eggs deposited in or on rocky substrates; no current required	Eggs deposited on plants	Eggs deposited in holes, cavities	Eggs deposited in nests of mud, sand, or plant debris	Eggs deposited over a variety of substrates	Low (< 25 JTU)	Moderate (25-100 JTU)	High (> 100 JTU)
Largemouth bass			X		X	X	X						X		X				X						X			X	
Spotted bass		X			X	X		X		X		X			X				X						X			X	
Black crappie		X	X		X	X	X		X				X		X				X						X			X	
White crappie		X	X		X	X	X		X				X		X				X						X				X
Bluegill		X	X		X	X	X			X			X						X						X			X	
Warmouth			X		X	X	X	X					X		X				X						X				X
Slough darter			X		X	X							X						X				X					X	
Common carp		X	X			X	X	X			X		X						X				X						X
Smallmouth buffalo	X	X	X		X	X		X		X	X		X		X				X				X					X	
Channel catfish	X	X	X		X	X		X			X	X		X	X				X					X					X
White sucker		X	X	X	X			X			X	X	X	X				X			X							X	
Northern hogsucker	X	X		X	X							X						X			X						X		
Striped bass	X					X			X	X	X					X		X		X								X	X
Rainbow trout	X	X		X	X		X		X	X		X	X	X	X		X				X						X		

[a]Categories from Hokanson (1977)

[b]Categories from Balon (1975)

[c]Common names from Robbins et al. (1980)

Figure A-1. Sample species classification using guilding criteria.

	Riverine						Lacustrine																						
	Habitat			Stream size			Habitat					Cover					Temperature[a]			Spawning[b]							Turbidity tolerance		
							Near-shore		Open-water																				
Species	Riffles, runs	Pools, eddies	Backwaters, bayous, oxbow lakes	Small (< 5 m); order: 1-3	Medium (5-30 m); order: 2-6	Large (> 30 m); order: 5+	Shallow (≤ 5 m)	Deep (> 5 m)	Surface (< 5 m)	Mid-water (5-15 m)	Deep (> 15 m)	Rocky substrate	Aquatic vegetation	Cut-banks	Logs, brush, debris piles	No special cover needs	Cold (< 20°C)	Cool (20-28°C)	Warm (> 28°C)	Free-drifting eggs, no substrate req.	Eggs deposited in or on rocky substrates; current required	Eggs deposited in or on rocky substrates; no current required	Eggs deposited on plants	Eggs deposited in holes, cavities	Eggs deposited in nests of mud, sand, or plant debris	Eggs deposited over a variety of substrates	Low (< 25 JTU)	Moderate (25-100 JTU)	High (> 100 JTU)

[a] Categories from Hokanson (1977)

[b] Categories from Balon (1975)

Figure A-2. Guilding criteria for freshwater fishes.

other models can be used. The assumptions, limitations, accuracy, and data requirements of each HSI model should be evaluated in relationship to the objectives and constraints of the individual HEP application prior to selecting a particular HSI model. Any indices of habitat quality developed specifically for the study area also should be considered. In order to determine if region-specific models, or the models presented in this series, are suitable for a particular HEP application, the three general steps of HSI model construction listed in U.S. Fish and Wildlife Service (1981) should be reviewed (i.e., establish the model objectives, identify the habitat variables that are related to the model objectives, and define model relationships that combine measurements of the habitat variables in such a way that model objectives are achieved).

A "standard" HSI model for HEP does not exist. The models in this series are a starting point for the development of models for a specific study. The evaluation and use of the fish HSI models presented in this series to complete the three steps of HSI model construction for site specific HEP applications requires an understanding of model attributes and limitations and methods for model modification. This information is provided in the next two sections. Sources of additional species-habitat information for developing or modifying HSI models are described in U.S. Fish and Wildlife Service (1981).

Examples and Limitations of HSI Models

The attributes and limitations of HSI models necessarily reflect the attributes, limitations, and goals of the HEP approach to environmental assessment. HSI models used with HEP must consist of habitat variables: (1) whose importance to the evaluation species can be documented (U.S. Fish and Wildlife Service 1980a); (2) that are quantifiable; (3) whose values can be measured or predicted under various habitat conditions in the present and, if necessary to meet project goals, the future.

Fish models currently included or referenced in this series are of three general types: (1) regression models that predict a measurable response, such as standing crop or harvest, from environmental variables; (2) descriptive (verbal) models that assign an HSI based on the presence or absence of specified levels of environmental variables; and (3) mechanistic models that describe suitability index ratings for individual variables and aggregate those ratings into an HSI that is based on hypothesized causal relationships between variable values and habitat suitability. These three types of models are discussed separately below.

Regression models. Regression models are commonly used for resource planning in reservoirs (e.g., Leidy and Jenkins 1977) and streams (e.g., Binns and Eiserman 1979). Regression models developed by the National Reservoir Research Program have been used as planning tools since the late 1960's. Regression models identify the major habitat features within a particular set of streams or reservoirs that "explain", or account for, most of the variation in standing crop or harvest within the chosen data set. Regression models are appealing and useful planning tools because predictions based on the model have known accuracy levels in relation to the original data sets. They can give an indirect but relatively accurate answer to specific planning questions (Rornesburg 1981). Regression models are an example of the empirical approach to problem solving which Rigler (1982) described as essential for the development of new predictive theories in environmental science. The major limitation of regression models is that, although they may indicate which environmental variables are important in determining the response of a species, they do not explain why. If the models are used to make predictions from a new data set and fail, there are few clues as to the cause of failure. Regression models also are relatively inflexible; they cannot be readily modified to include site specific considerations without completing a new regression analyses of the new data set. One method to obtain maximum accuracy from regression models is to limit their use to cases where environmentai conditions are similar to those present in the data base used to construct the model. If this is not possible, a simple hypothesis of why the regression model variables are important should be developed. If the new environmental conditions being evaluated seem consistent with the hypothesis, the model would be used to make predictions from the new data set.

Regression HSI models have been developed for sixteen warmwater species for HEP applications in reservoirs (Aggus and Morais 1979). The National Reservoir Research Program maintains a set of regression formulas for predicting fish standing crop and harvest in reservoirs. These models can provide relatively rapid determinations of studying crop or harvest under pre- and post-project conditions. They do not require extensive field sampling because most of the variable measurements usually can be based on data obtained from construction agencies. The coefficient of determination (R^2) and number of reservoirs used for each species or species-group regression equation are given. This provides a description of the efficiency of the regression in explaining variability in standing crop or harvest in the original data set. Limitations of these models coincide with the limitations presented above for regression models in general.

Descriptive models. Descriptive HSI models in this series consist of environmental variables that are judged most important to the species by the model author(s). Specific cause and effect relationships between variables and life requisites, such as food, are not hypothesized. Habitat ratings are based on the presence or absence of optimal values of selected variables or on combinations of specific levels of selected variables. Examples of these two types of descriptive models are Additional Model 1 for the channel catfish (McMahon and Terre11 1982) and the models presented in McConnell et al. (1982). These types of descriptive models: 1) provide a rapid means of comparing habitat conditions; 2) are easily modified to meet project goals; 3) generally require few or no extensive field measurements; and 4) can be utilized as low effort evaluation tools prior to the application of more detailed models. Major limitations are that they provide limited insight into how the variables interact and have unknown accuracy. These models can be made more representative of perceived species-habitat relationships by increasing the detail of the word descriptions that comprise the model (U.S. Fish and Wildlife Service 1981).

Mechanistic models based on suitability indices. Models based on the aggregation of suitability indices for selected habitat variables follow the "mechanistic" approach to HSI model development described in U.S. Fish and Wildlife Service (1981). Mechanistic models are constructed as a hierarchical set of hypotheses about species-habitat relationships based on the documented opinion of model author(s). The hypotheses are developed in four stages during the process of model construction. First, variables are chosen that represent key habitat features known to affect the growth, survival, abundance, standing crop, distribution, or other measure of habitat quality for a species. Second, the relationship between each habitat variable and carrying capacity (= habitat suitability) for the species is translated into a graphic hypothesis (= suitability index graph). Third, habitat variables are aggregated via mathematical equations into the model components of Food, Cover, Water Quality, and Reproduction.[2] Last, the model components are aggregated into a species HSI equation that yields a single numerical description of habitat suitability. Because specific data on variable interactions are often lacking, model builders may have to develop assumptions on how the variables combine to determine habitat suitability. These assumptions are translated into simple mathematical language. The use of mathematical language results in a model that can produce an index with several decimal places. The number of decimal places does necessarily imply a certain level of accuracy.

Mechanistic models have several attributes that make them useful as tools in environmental planning. The basic model structure allows incorporation and integration of a wide variety of existing knowledge and hypotheses about species-habitat relationships. Therefore, a species HSI can be determined for a wide variety of existing and potential habitat conditions. In addition, the model structure enables environmental planners to easily track habitat changes that have the most effect on overall habitat suitability for a species. Tracking can occur between different sites at one point in time or for one site at several points in time. Mechanistic models can readily be modified to incorporate new information on habitat requirements and site specific considerations, thereby providing the user with a high degree of flexibility to meet project goals. To a large extent, however, the flexibility is a result of the subjective use of existing data. The subjectivity involved in model development and the level of precision likely to be obtained with both the original and altered models should be understood prior to using or modifying a mechanistic model.

Potential sources of subjectivity in model development are listed below and described in detail: (1) determining which variables should be included in the model; (2) developing suitability index graphs from often contradictory or incomplete data; (3) incorporating information for similar species or different life stages in the suitability index graphs; (4) determining whether

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[2]An "other" model component can be added to incorporate model variables that cannot be classified according to one of these four components. Model variables also can be classified into life-stage components to form a life-stage model structure, if so desired.

or not highly correlated variables really affect habitat suitability independently and which variables, if any, should be eliminated from the model; (5) determining when, where, and how model variables should be measured; and (6) converting assumed relationships between variables into mathematical equations that aggregate suitability indices for individual variables into a species HSI.

Many factors potentially can affect carrying capacity for a species. Model builders must decide which factors are most important within the following constraints. First, available information must be sufficient to develop a hypothesized relationship between the potential model variable and some direct or indirect measure of carrying capacity or habitat quality for a species that is acceptable to model users. For example, turbidity was chosen as a model variable in the creek chub HSI model (McMahon 1982) because abundance of creek chubs varies indirectly with turbidity level. Second, model variables must be quantifiable and have a measurable and predictable value under various habitat conditions to qualify for use in HSI models with HEP. When factors are believed to affect the carrying capacity of a habitat for a particular species, but the species' response has not been quantified or measured or where there is insufficient information to indicate a cause-effect relationship, authors tend to eliminate the factors as potential model variables.

Several types of measurable responses to changes in habitat variables are usually reported in the literature. For example, changes in spatial distribution of a species may be associated with changes in one variable while differences in species survival may be associated with changes in a different variable. The measurable response by individuals or populations to changes in each model variable, as reported in the literature, must be converted to a suitability index for the variable. The way that this conversion is made is determined by the author and may vary between models. Assumptions about the reported relationship between the species response and the suitability index of a variable are critical in model interpretation and are presented with HSI models.

Data on species with presumably similar habitat requirements that occur in the same habitat as the species for which the model is being developed can be used to develop suitability index graphs. This usually occurs when data on the selected species are unavailable. Assumed similarities in habitat requirements between the similar species and the selected species may or may not have been proven.

Cause and effect relationships between impacts and changes in habitat variables often are unclear. Species responses often are correlated with changes in several environmental variables, which may be highly correlated with each other. The model builder must decide which, if any, of the correlated environmental variables should be included in the model. However, the decision often must be based on experience and intuition. Variables might be selected on basis of ease of measurement or how much variability within the relationship is accounted for by the variable.

Changes in a habitat variable included in the model are expected to result in measurable and predictable species responses under controlled conditions. For example, fish kept at different, but constant, temperatures may exhibit different growth rates. Applying this type of experimental data to natural conditions is less certain because temperature cannot be held constant. Instructions for when, where, and how to measure the variable are required'.

Assumptions about how model variables cumulatively affect habitat suitability must be made and converted into mathematical language in order to aggregate the individual variable suitability indices into an HSI. Model variables can be assigned different weights. Weighting factors usually reflect perceived importance, rather than the results of rigorous experiments. Weighting is determined, to a large extent, by the personal experience of the model builder and the advice of species experts contacted during the model building process. Qualitative statements, such as "Complete utilization of available food resources requires that adequate resting cover be located nearby" are converted into mathematical expressions. Conversion to mathematical form does not decrease the subjectivity, but it does allow different model users to arrive at the same HSI if they start with the same set of habitat measurements. If the HSI produced by the model does not seem reasonable, but the verbal assumptions on variable interactions do, the mathematical statement of the assumptions can be changed until the revised equations give a more believable HSI, while remaining consistent with the assumptions. For example, many model builders use a geometric mean to express how a variable value with low suitability can be compensated for by one or more variable values with high suitability. If this method allows for too much compensation, the value of the exponent on the geometric mean can be increased, which will lower the answer for the variable combination.

The major limitation of mechanistic HSI models, based on suitability index graphs, is that the accuracy of their output cannot be directly verified. Since real values of HSI do not exist and cannot be measured, model accuracy has been tested by comparing model outputs (i.e., HSI) with measureable indices of carrying capacity, such as fish standing crop or production. Model accuracy in predicting measureable indices of carrying capacity depends on the accuracy of the data base, the various assumptions used to construct the model, and the relationship of the measureable index to carrying capacity. The data bases used to construct mechanistic HSI models are quite variable, both in quantity and quality. HSI models for intensively studied fishes usually contain more variables and supporting data than other models. Preliminary tests of mechanistic HSI models by the Georgia, Maine, Oklahoma, Oregon, and Utah Cooperative Fishery Research Units have indicated that the accuracy of the models in predicting standing crop of individual fish species is often low. However, most of the testing was done at a few sites in restricted geographical regions and, usually, at one point in time. These tests indicated that, for a given data set, model performance can sometimes be improved by reformulating the mathematical descriptions of how suitability indices of individual variables are combined to determine overall habitat suitability. The low predictive accuracy of present mechanistic HSI models may be considered a major weakness that limits their utility as a planning tool. This justifiable criticism, however, does not take into account the difference in the accuracy requirements between science and planning activities (see discussion by Romesburg 1981). Science requires strict, often statistical, measures of accuracy whereas planners often must judge model accuracy in terms of the goals set by the planning program, because the level of knowledge is insufficient to do otherwise (O'Connor and Patten 1967; Romesburg 1981). The urgency of planning often necessitates the use of information that may not be highly accurate. Mechanistic HSI models provide a means of displaying logical, but scientifically untested, cause and effect relationships between variables. Watt (1962) classified this type of model as an a priori mociel, constructed on a priori assumptions about causal relationships, where precise and accurate data are incomplete. Mechanistic HSI models, like many planning tools and a priori models in general, have predictive powers only within accuracy levels that are relative to the goals of the planning program (Romesburg 1981). These models cannot be "proven" right or wrong, but the reliability of the model output can be tested by reformulating the assumptions and examining the new model behavior relative to how well it meets the acceptable and ideal model objectives for the planning program (U.S. Fish and Wildlife Service 1981:Chapter 3.1).

The validation process for mechanistic HSI models evaluates model output at four different acceptance levels: (1) review by model author; (2) analysis of model behavior with sample data sets that mimic various habitat scenarios; (3) review by species authorities; and (4) testing the model with actual field data (U.S. Fish and Wildlife Service 1981). Results of tests of model accuracy and precision, when available, are included with each HSI model in this series. All mechanistic HSI models currently have been validated to level 3, although review by an authority does not necessarily mean the authority agrees with all model assumptions or that the model can predict any measureable index of carrying capacity, such as standing crop. Continued sensitivity analyses and field tests are underway to improve model accuracy and precision and to evaluate various approaches to model development. The results of these analyses will serve as a quality check on the model and may make it possible to further refine the model so that it will meet a higher acceptance level.

It should be possible to determine or improve the accuracy of the models with well-designed tests. For any set of species' responses that the model can be tested against, such as standing crop of fish, an index with a higher correlation with the response than the given HSI can almost certainly be developed by statistical analysis. This index may have greater accuracy in predicting values from the original data set but may or may not have more accuracy in predicting values for data sets collected in different regions under different conditions. This is especially true when the range of values for a variable is greater in the new data set. In addition, the species response that is measured for the original data set may not be the appropriate measure of carrying capacity in alternative model applications.

Summary. The three types of models have different strengths and weaknesses. Regression models may provide high predictive accuracy for a data set, but the user must apply sound judgment to determine if the same accuracy can be obtained when the model is used to make predictions for a new data set. The simple descriptive models have low demands for information and quantify subjective decisions about optimal levels of habitat-related variables.

However, model resolution is limited to a few discrete HSI ratings (e.g., 0.3, 0.7, 1.0), and the oversimplified format tends to camouflage the assumptions on ecological processess used to determine the ratings.

Mechanistic models provide a way to display and integrate a wide variety of assumed cause and effect relationships between variables when determining habitat suitability. The accuracy of this type of model may be low or unknown, but the reliability may be sufficient to use the model as a planning tool. When this type of model is used to make predictions, the reasons for successful and unsuccessful predictions may be difficult to determine because it may be diff cult to isolate the influence of individual assumptions.

Levins (1966) stated that mathematical models used in population biology have three major characteristics: precision; generality; and realism. Furthermore models tend to be weak in one of these characteristics. Because no mode is perfect, clear objectives are necessary in order to determine which model weaknesses are acceptable for the planning task and, therefore, which type of model to use. Specific strategies for model development to meet planning objectives are discussed by Farmer et al. (in press).

Model Modifications

One potential problem in application of any of the three model types is the difficulty in measuring all the habitat variables in the model(s). This problem usually can be overcome by modifying the measurement technique suggested for the variable and estimating the variable value using the data obtained with the modified technique. This alteration is especially useful with variables that require long term monitoring or some form of spatial or temporal averaging for accurate measurement. For example, accurate estimation of "maximum monthly average turbidity during the summer" in the channel catfish model (McMahon and Terrell 1982) requires monitoring of turbidity during the summer months. Such monitoring could be expensive and would apply only to the period sampled. The references cited in the model indicate that turbidity may affect channel catfish standing crop. However, none of the data are directly related to turbidity, as defined in the model. The need to accurately estimate the level of the turbidity variable is not established in the model documentation, and the accuracy level of the original model is unknown. If the model user feels that one or a few turbidity measurements will provide a sufficiently accurate estimate of the variable value to meet model application goals, the simpler estimation technique should be used. In some cases, values for model variables can be estimated from measurements on similar water bodies, rather than measured on site.

It may be possible to modify and improve regression models by stratifying heterogeneous data sets into more homogenous subsets. For example, Leidy and Jenkins (1977) and Jenkins (1982) found that regression models explained a greater part of the variability in standing crops of fishes in reservoirs when the reservoirs were grouped by storage ratio and chemical types than when the reservoirs were analyzed together. Subdivision of the original data set should be directed at producing a subset of observations that are as closely related as possible to the conditions at the proposed model application site.

The statistical analysis is run on the new data subset and the new regression model used in place of the original model.

Descriptive models, based on the assumption that the presence or absence of optimal ranges of a few variables is sufficient to describe habitat suitability, do not have a complex causal structure. They do not provide specific hypotheses about how variables cumulatively determine habitat suitability. These models are easily modified so that they match values of indicators of habitat suitability, such as hatching success or production, observed in areas similar to the model application site. Descriptive models can be modified by group experience using the "Delphi" technique described by Zuboy (1981).

Mechanistic HSI models that derive suitability index ratings for individual habitat variables and use an equation to combine these ratings also can be modified. Including more variables in a model does not necessarily result in a model with greater predictive power and may, in fact, cause the model to be less reliable than a simpler model (Holling 1978). In fact, there is a higher probability of making an incorrect assumption about variable interactions when the number of variables is large. In addition, a great expenditure of time and effort may be needed to measure a large number of variables. Three methods to reduce model complexity for site specific applications are discussed below.

One method to simplify a mechanistic HSI model is to define an evaluation species in such a manner that only the model component that appears to have the greatest influence on habitat suitability is used. The combination of life stage (e.g., fry and juvenile) or life requisite (e.g., food and water quality) components into an overall rating of habitat suitability is based primarily on the experience and intuition of the authors, not experimental data. These models are useful for exploring relationships between variables related to life stage habitat quality, but may not be useful for meeting some planning needs. Use of a single component for the total species HSI avoids the problem of making erroneous quantitative assumptions about the relationship between model components and requires only a decision about which component is most important for determining the suitability of the conditions being analyzed. The selected component may be the one that will be affected the most by the land use alternatives or the one that is assumed to have the most influence on population levels.

A second method to reduce model complexity is to limit the number of variables used while maintaining the model structure. This method can be used when the acceptable verification level is low; e.g., the model appears to provide reasonable output to the authors or selected individuals familiar with the species but has not been verified with actual field data. The first step is to diagram the model structure to show how the variables are combined to determine overall habitat suitability (Fig. A-3). Selected variables are deleted and the remaining variables reexamined. The original relationship between habitat variables, model components, and the HSI is retained in the new model. For example, a potential user of the model described in Figure A-3 may have data on three variables: turbidity; percent pools; and substrate type. These data are sufficient to develop a very abbreviated rating for the four life requisite components identified in the original model. Although the model has been simplified, much of the reasoning behind the original model

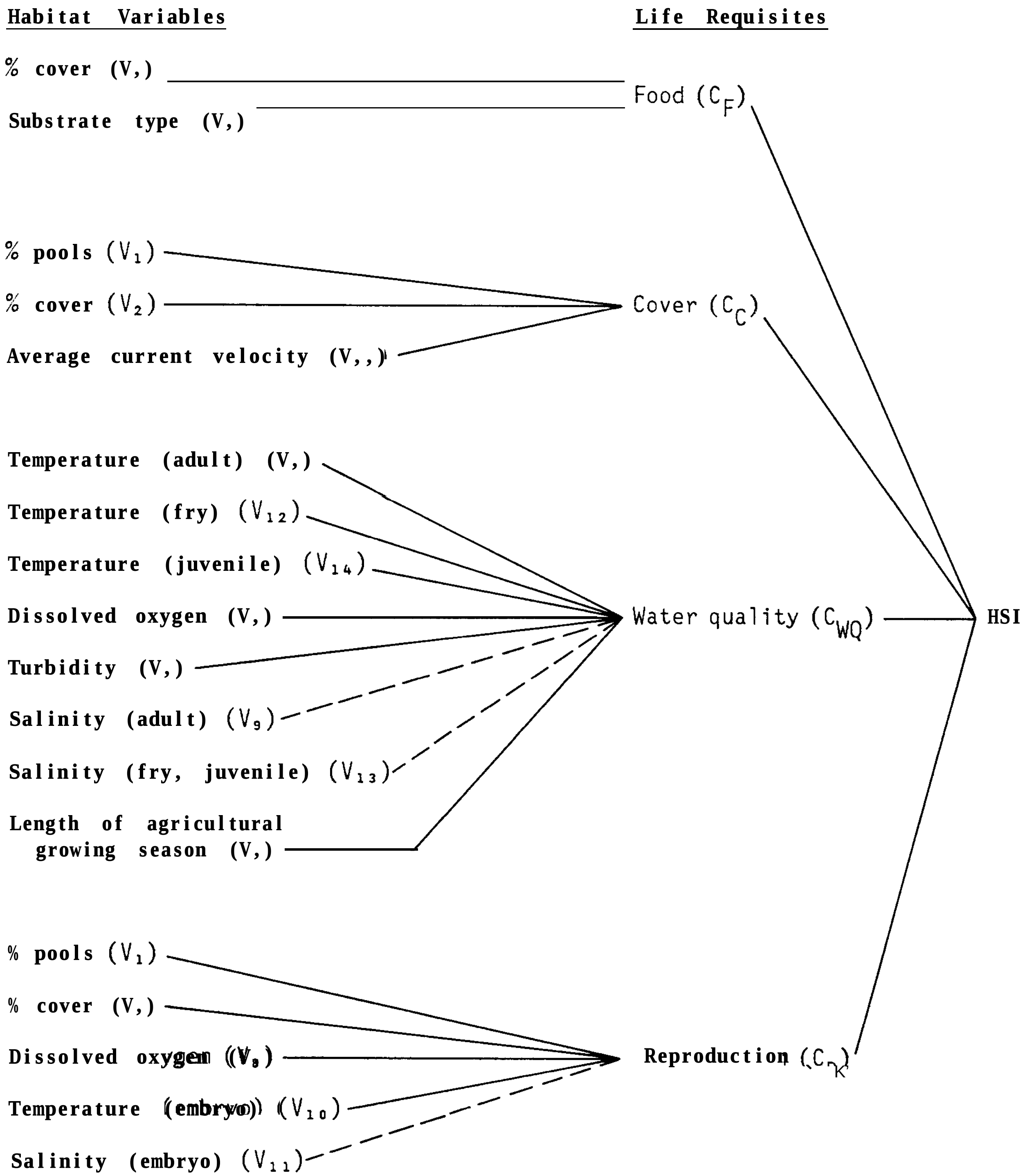

Figure A-3. Example diagram of model structure showing how model variables combine to determine an HSI. Dashed lines indicate optional variables.

structure still applies, reducing the amount of documentation needed for the new model. This approach also can be used to include additional variables as new habitat requirement information is obtained or to add variables that affect habitat suitability at a particular site but which were not contained in the original model.

Variables with the weakest relationships to habitat suitability are likely candidates for deletion from the model for site specific applications. For example, a habitat variable with a strong relationship to species survival, such as dissolved oxygen or pH, would be retained in the model if the proposed application site had levels known to negatively affect species survival. If the levels did not affect species survival, the variable could be dropped from the model. A variable that is in the model because fish seem to prefer certain levels of the variable, even though the consequences of a variabie being outside the prefered range is uncertain, would be another likely candidate for elimination. Variables that will not have different suitabilities in the range of conditions being compared also may be deleted.

Statistical models can be used as screening tools to reduce the number of model variables. If a suitable indicator of carrying capacity (e.g., standing crop, production, or angler harvest) is available for water bodies similar to those being evaluated, it may be possible to develop a statistical model that predicts the indicator of carrying capacity based on the environmental variables included in the original mechanistic model. Only those variables that are statistically important in determining carrying capacity would be included in the final HSI model. The original model structure is retained. With this approach, the statistical model is used to identify the most important variables to include in a mechanistic HSI model, rather than to make predictions of the selected measure of carrying capacity at the model application site.

The third method of reducing model complexity to meet specific study objectives is to develop a statistically calibrated HSI. The variables that will have their suitability changed as a result of a specific impact are aggregated into an index, using the original model structure. Sites are located that represent a wide range of variable values, and a statistical model that predicts a measurable response, such as standing crop, from the index is determined. The HSI is the value of the measurable response predicted with the original index divided by a maximum value for the response. If possible, the statistical model should be developed using data from similar water bodies in the geographical area where the model is to be used. An example of using a calibrated habitat index to quantify relative capacity of a stream to support fish is presented by Newcombe (1981). Once an index has been shown to be a reliable predictor of a measurable response, such as standing crop or production, the predicted measurable response would normally be changed back to an HSI only if it was necessary to use HEP to compare impacts with species for which similar reliable models did not exist.

DETERMINING THE HSI FOR AVAILABLE HABITAT

Once an HSI model that meets study objectives has been developed or selected, model variables must be estimated from field measurements or historical data. Sources of information about measurement techniques for physical and chemical variables (e.g., dissolved oxygen, turbidity, and conductivity) are summarized by States et al. (1978) and Lind (1979). Methods for evaluating and minimizing sampling variability are described in U.S. Fish and Wildlife Service (1980: Appendix B). Potential data sources for selected variables and suggestions for recording and analyzing aquatic data are provided below. Proper recording and documentation of model input data are especially important if model accuracy is to be evaluated.

Sample sites are chosen to represent larger areas of similar habitat. If HEP will be used to characterize future conditions, the similarity of the future condition of the sample site to the future condition of the larger area that the sample site represents must be considered. Factors to consider in selecting the location and number of sample sites include the variability of the area being sampled, the required accuracy of the application, and time and cost constraints.

Selecting Riverine Sample Sites

Selection of sample sites in riverine habitats can follow one of two major strategies or a combination of the two: (1) selection of one or more reaches with habitat conditions that are representative of a particular section of the study area; or (2) selection of one or more reaches with habitat conditions that are unique and critical to the survival of a fish population within the study area.

As a general rule, a representative reach should be 10 to 14 times longer than the average channel width in order to include two sequences of channel features (Bovee and Milhous 1978). Once a representative reach has been identified, most habitat variables can be measured along transects. Transect measurements are used in several stream evaluation methods (e.g., Herrington and Dunham 1967; Duff and Cooper 1976; Bovee and Milhous 1978). The number of transects needed within a representative reach is dependent on the degree of variation in the model variables and the level of reliability required for the study. At least 10 evenly spaced transects per representative reach are recommended for use in sampling habitat variability. Data from these 10 transects can be used to determine if a greater or lesser number of transects are needed to adequately sample the model variables necessary to calculate an HSI.

Selection of a critical stream reach is dependent on knowledge of a species' habitat requirements. The critical reach should contain unique features that are limiting to a particular life stage or the species in general (Bovee and Milhous 1978). For example, knowledge that spawning habitat is in short supply and limited to one area would lead to the identification of that area as a critical reach. Spacing of transects within representative or critical reaches can be determined by the formula $D = L/(n - 1)$ where D = distance between each transect, L = length of reach, and n = number of transects.

Selecting Lacustrine Sample Sites

Selection of sample sites in lacustrine habitats is based on considerations similar to those used in the selection of representative or critical reaches in riverine habitats. Transects provide a convenient method to sample variables that change horizontally, such as vegetative cover and substrate composition. However, many lacustrine habitat variables change vertically, such as water temperature and dissolved oxygen, and vertical profiles may also be necessary. Transects can be established perpendicular to a center line through the long axis of the lake and marked with bouys. Transect spacing is determined by the formula used in riverine sampling, with L equal to the long axis.

Recording Field Data

Previously developed data sheets may be adequate for recording habitat data for the models selected. However, it may be necessary to develop new data collection procedures and recording forms if a model application requires data not usually collected by the user. Figures A-4 and A-5, at the back of this document, illustrate an example riverine data record and lacustrine data record, respectively, for quantitative habitat measurements and qualitative observations. These data records and instructions for completion incorporate some of the techniques of the transect-based methodologies of Herrington and Dunham (1967), Dunham and Collotzi (1975), and Bovee (1978) and were developed primarily from our experience in the development and application of HSI models for channel catfish, creek chub, and cutthroat trout. The stream data record is oriented towards data collection in wadeable streams where the water is clear enough to see the bottom. The data records display more data than necessary for many site specific applications. Each record contains a complete location description to accommodate data acquisition by more than one field crew. These records are a starting point for development of project specific field forms. Specific variable measurement techniques and example field forms for use with the trout habitat model described by Binns and Eiserman (1979) are provided by Binns (1982).

Variable Estimation for Existing Conditions

Common HSI model variables used in this series can be divided into categories including morphometric, hydrologic, cover, water quality, and other variables. Techniques that can be used to determine values of model variables from the data records (Figs. A-4 and A-5) are provided. When variables cannot be measured at the time and place specified in a model, it may be possible to estimate their value from measurements made at other sites or times or from measurements taken on similar water bodies. The procedure used to obtain variable values should be documented. Measurement techniques that are described with the data records are not repeated here.

Morphometric and hydrologic variables. Values for most of the variables listed below can be estimated from data routinely collected by State water resource or conservation agencies, reservoir operating agencies, or the U.S. Geological Survey.

Average annual base flow - $\frac{\text{Average 30 day low flow}}{\text{Average annual daily flow}} \times 100$

Average discharge - average volume of water passing a specified point during a specified time period. Average annual discharge estimates can be obtained from U.S. Geological Survey gauging station records. Accurate measurement of discharge at a particular time on ungauged stream sites requires precise data on stream cross section area and water velocities. Techniques and equipment necessary to measure discharge are described in Bovee and Milhous (1978).

Average maximum stream depth - arithmetic mean of the maximum depths from each transect (page 2, riverine data record).

Average stream width - arithmetic mean of the stream widths at each transect site, measured at a specified time and flow (page 3, riverine data record).

Average velocity - arithmetic mean of all velocity measurements taken at a depth 0.6 of the way from surface to bottom, in a specified area, at a specified flow and time of year (page 2, riverine data record). Velocity can be estimated by timing the flow of marking dye in a stream, as described in Binns and Eiserman (1979). Velocities in the water column follow a known distribution; Bovee and Milhous (1978) provide a graph for estimating velocity at one depth from a measurement taken at a different depth.

Maximum depth - from page 1, lacustrine data record.

Mean depth - from page 1, lacustrine data record.

Reservoir drawdowns - the change in reservoir elevation during a specified time interval. Data on drawdowns are usually available from the agency that operates the reservoir.

Reservoir flushing rate - page 1, lacustrine data record.

Shoreline development factor - page 1, lacustrine data record.

Storage ratio - page 1, lacustrine data record

Stream gradient - page 1, riverine data record.

Surface area - page 1, lacustrine data record.

Water level fluctuations - page 1, lacustrine data record.

Cover variables. Methods for estimating these variables from transect information entered on the data record are described below. Ocular estimates, based on a visual inspection of the sample site, may be substituted for transect data. This method will speed up the field sampling but will be less precise. Techniques used to determine values of variables should be documented.

Average percent of streambank covered by rooted veqetation - subtract the percent bare ground recorded for each bank from 100% (riverine data record, page 1) and calculate the arithmetic mean of the remainders.

Average pool class rating - multiply the length of the transect segment crossing the pool by the rating for each pool section rated (riverine data record, page 1). Divide the sum of the products by the sum of the segment lengths to obtain the average rating.

Average size of substrate - weighted (by length of transect segment) arithmetic mean of substrate size(s) recorded on transect (riverine data record, page 2). If average substrate size will be used to evaluate salmonid spawning habitat, the Fredle number (Lotspeich and Everest 1981) may provide a better index of substrate suitability than average size of substrate.

Maximum percent of bottom covered by subsurface ice - maximum percent of bottom covered by ice at the end of a winter of average severity. This variable is not identified on the data records. It could be entered in the blank column under substrate (riverine data record, page 2) and recorded along transects at the time the maximum coverage occurs.

Percent backwater areas - calculate by dividing the sum of the lengths of transect segments where backwaters occur by the sum of the lengths of all transects and multiplying the quotient by 100. One of the blank columns on page 2 of the riverine data record can be used to record the occurrence of backwater areas. Percent overflow areas located off of the main channel can be calculated in a similar manner.

Percent cover - divide the sum of the lengths of all transect segments crossing the specified cover class by the sum of the lengths of all transects and multiply by 100 (riverine data record, page 1; lacustrine data record, page 2). Measurements should be taken at the specified time and flow for maximum accuracy. If location of cover (e.g., pools) is specified, include only measurements taken in specified locations.

Percent fine sediments (or percent fines) - the percent, by volume, of substrate composed of particles less than a specified size. If no size is specified, calculate the percent based on particles with a diameter of less than 2 mm. Diameter is measured along the long axis of the particle. A sieve with openings of the specified size is an effective way to separate the sediment. Samples should be taken to a depth of approximately 30 cm with a core sampler or bucket. Multiply the percent fines by the length of the transect segment for which the sample applies. Divide the product sum by the sum of all transect lengths. Values can be recorded in the blank column (page 2, riverine data record). Lotspeich and Everest (1981) describe difficulties with the use of percent fines in evaluating quality of salmonid spawning substrate and define an index (Fredle numbers) for evaluating spawning gravel that considers both average size (geometric mean) and size distribution of sediment particles.

Percent inundated vegetation - calculate the length of each transect segment where inundated vegetation occurs, and divide the sum of the segment lengths by the sum of all transect lengths (riverine data record, page 1; lacustrine data record, page 2).

Percent littoral area - percent of the water body or study area that is shallow enough to be inhabited by rooted aquatic plants. Plants do not have to be present. Values for this variable can be approximated by estimating the maximum depth that could be inhabited by rooted aquatic plants and determining the percent of the water body less than or equal to that depth. Areas with substrates incapable of supporting rooted aquatic plants would be excluded from the calculations.

Percent pools - divide the sum of lengths of transect segments where pools occur (riverine data record, page 3) by the sum of the lengths of all transects and multiply by 100. Measurements should be taken at a specified time and flow.

Percent of stream area shaded - arithmetic mean of percent shade estimates (riverine data record, page 1).

Percent substrate - sum the lengths of all transect segments that cross the specified substrate type, divide by the sum of the lengths of all transects, and multiply by 100 (page 2, riverine and lacustrine data records).

Percent substrate embeddedness - multiply the percent embeddedness recorded for each transect segment by the segment length, sum the products, and divide by the sum of all segment lengths (page 2, riverine and lacustrine data records).

Predominant substrate type - substrate type that is most common along transects (riverine data record, page 2).

Vegetation index - calculate the arithmetic mean of the percentages recorded for each type of riparian vegetation (trees, shrubs, grasses, and forbs) and bare ground for all transects. Use these means to calculate the index as described in the model. Data are recorded on the riverine data record, page 1.

Water quality variables. Water quality variables are included in the species models in a variety of forms, such as weekly average, monthly average, maximum, minimum, and range. The appropriate value for the variable should be determined for the specified time and part of the water body. Values can be calculated from the transect and profile data on the data records or from monitoring data. Most of the models do not consider toxic substance concentrations in conjunction with water quality variables. Brigham and Hey (1981) describe a stress function for rating water quality that includes 20 variables and considers the interaction of dissolved oxygen, pH, and toxic substances, such as ammonia, cadmium, and lead.

Alkalinity, dissolved oxygen, pH, and salinity - measurement techniques are referenced in the instructions for the riverine data record, page 2, and the lacustrine data record, page 3. If the water quality variable normally fluctuates over a time scale shorter than the interval specified by the model, use the measurement that results in the lowest suitability index.

Temperature - measure temperature and oxygen concurrently at time and locations specified in the models.

Total dissolved solids (TDS) - measurement techniques are referenced in the instructions for the riverine data record, page 2, and the lacustrine data record, page 3.

Transparency - usually expressed as the greatest depth at which a Secchi disk (Lind 1979) is visible to an observer from just above the water surface. Readings should be taken around midday.

Turbidity - measurement techniques are referenced in the instructions for the riverine data record, page 2, and the lacustrine data record, page 3.

Other variables.

Length of agricultural growing season - average number of days between the final killing frost of spring and the first killing frost of fall. This information can be obtained from National Oceanographic and Atmospheric Administration publications (1974, 1978) or from a local weather station.

Average daily invertebrate drift rate - the average daily number of invertebrates contained in a unit volume of stream discharge.

PREDICTING FUTURE HSI'S

Determining habitat suitability indices for future years requires the estimation of future habitat conditions. There are a variety of possible methods for forecasting aquatic habitat variables, ranging from very simple to very complex. Not all forecasting problems call for the use of mathematical models. In some cases, it may be appropriate to formulate a consensus projection of future conditions through use of the Delphi process, as described by Zuboy (1981). The user must determine the level of detail necessary for a particular project. There are no definitive techniques. Many of the predictive models cited below are applicable only under certain conditions. The user should understand the underlying assumptions before attempting to apply any of the models.

Comprehensive water quality simulation models have been developed for riverine, lacustrine, and estuarine environments. Water temperature, dissolved oxygen concentration, and the concentration of various conservative (e.g., total dissolved solids) and nonconservative (e.g., plant nutrients) constituents are among the variables that can be predicted. Simulation models are generally most helpful in cases where a large number of alternatives will be considered, because the cost of acquiring, calibrating, and verifying a simulation model is usually very great in comparison to the cost of actually applying it (Grimsrud et al. 1976). Data acquisition and input to computers also are burdensome in some cases. Grimsrud et al. (1976) provided a very useful review and evaluation of water quality models available as of 1975. Their review included simplified models that can be applied without the aid of a computer. Model evaluation criteria included applicability, data requirements! initiation and utilization costs, accuracy, and ease of application. The reader is referred to this document for a more detailed discussion of these models. More recently developed models are the Stream Simulation and Assessment Model: Version IV (SSAM IV) (Grenney and Kraszewski 1981) and a model for river-reservoir systems (U.S. Army Corps of Engineers 1978). A more advanced version of the reservoir component of the latter model also is available (Environmental Laboratory 1982). Many water quality simulation models are compartmentalized into submodels which can be applied independently. This flexibility greatly increases their utility.

Additional methods and sources of information for predicting aquatic habitat variables are presented below.

Temperature

In most regions, weather and, as a consequence, water temperature are highly variable between years. This makes it difficult to define the "normal" or "typical" temperature cycle unless long term water temperature data are available. Temperatures of selected surface waters (mostly rivers and streams) have been monitored for periods ranging from several to many years (Blakey 1966; Pauszek 1972). Compilations of temperature data are available for surface waters in Alabama (Avrett and Carroon 1964), Illinois (Harmeson and Schnepper 1965), Mississippi (Golden 1959), Montana (Aagaard 1969), North Carolina (Woodward 1970), Pennsylvania (Mangan 1946), Texas (Rawson 1970), Utah (Whitaker 1971), and Wyoming (Lowham et al. 1975). Such historical records may no longer be applicable if subsequent human activity has caused substantial changes in the drainage basin. Possible human actions that can affect water temperatures include thermal loading, impoundment, altered flows, deforestation, and changes in runoff patterns.

Long term climatic data are available for most localities in the United States. These data, combined with information on flows, basin configuration, nearshore topography, and vegetation, can be used to characterize the average or expected thermal regimes for lakes and rivers. Some general guidelines and a number of potentially useful references are cited below.

Seasonal changes in air and water temperature typically follow a sinusoidal curve. (This pattern is interrupted during winter in lakes and rivers that ice over). Water temperatures generally mimic air temperatures, but with a delay. This phase shift and the relative amplitudes of air and water temperature curves depend on morphometric and hydrologic characteristics of the water body concerned and on the degree of shading and wind-mixing. Air temperature records can be used to predict water temperatures in the surface (epilimnial) layer of lakes and reservoirs (Sette 1940; McCombie 1959) and in rivers (Kothandaraman 1972), provided that the air-water temperature relationship can be calibrated with data from a nearby water body that is similar to the one for which predictions are to be made.

Different investigators have developed different calibration procedures. Sette (1940) determined the relationship between the rate of change of water temperature and the difference between air and water temperature for an existing reservoir and then used this relationship, together with local air temperature data, to predict surface water temperatures in a proposed reservoir of similar dimensions and in the same area. McCombie (1959) calculated regression equations relating mean monthly surface water temperatures to mean monthly air temperature for several northern lakes, using measurements made over a series of years. Separate regression analyses were performed for each month because the relationship between average water temperature and average air temperature was different for warming and cooling phases. The resultant equations can be used to estimate water temperatures in any past year for which air temperatures are available or for an "average" or hypothetical air temperature regime. Kothandaraman (1972) presented a relatively simple mathematical model for predicting seasonal change in water temperature from air temperatures. The model is based on the sinusoidal trend in both air and water temperatures and on the correlation between nonseasonal (random) variations in the air and water temperatures. The model performed well when parameterized for one site on a river and applied to another site 44 miles downstream.

The relationship between air and water temperature for streams depends on the degree of shading, ground water inflows, and channel configuration (Blakey 1966). In Oregon, exposed streams typically have monthly mean temperatures that exceed monthly mean air temperatures during summer, unless they derive much of their flow from cold springs; more sheltered streams, and those that are largely spring-fed, remain cooler than the air (Moore 1964). Moore (1964) also noted that streams with an east-west orientation tend to be warmer than north-south flowing streams in the same area. The warming effect of deforestation has been documented for streams throughout the United States (Brown and Krygier 1970).

Laythe (1958) listed extensive data on air and water temperatures for the Snake River. These data have not been analyzed but could be used to establish the relationship between air and water temperature for a moderately large river. Air and water temperatures were compiled for rivers and streams in Pennsylvania (Mangan 1946) and Utah (Whitaker 1971).

Still simpler methods are available. For example, if the surface does not become covered with ice, an annual temperature curve can be defined by specifying maximal and minimal water temperatures and the dates on which these extremes are reached and then driving a sine curve through these points. If the surface does ice over, the maximum temperature, date of maximum temperature, and approximate length of the ice-free season must be known. Ward (1963) described a least squares approach for fitting a sine curve to stream temperature data. Kothandaraman and Evans (1970) used the same approach to represent annual temperature variations at different depths in a reservoir. A first order sine curve accounted for more than 95% of the annual variation in water temperature in each case. If greater precision is required, higher order harmonics can be used (Kothandaraman 1972; Straskraba and Javornicky 1973); however, this is rarely helpful for characterizing a "typical" thermal regime.

Mechanistic temperature models also can be used to predict thermal regimes. These methods make a more thorough and explicit accounting of heat exchange processes than do the empirical/statistical techniques described above. Data requirements are, accordingly, somewhat greater. The approaches outlined by Burt (1957), Raphael (1962), Delay and Seaders (1966), and Brown (1969) are patterned after the energy budget work of Anderson (1954). Burt (1958) described methods for evaluating terms of a heat budget equation and presented solutions for two Snake River reservoirs. Precise, site specific measurements are required in order to accurately predict daily temperatures in small streams, especially if they are unshaded (Brown 1969). Diurnal temperature variations in small streams may exceed 14° C (Blakey 1966).

Prediction of temperatures in aquatic habitats that are not thermally uniform is especially difficult. Shallow zones warm and cool more rapidly than deepwater habitats, but the temperature patterns which develop are often transitory. Most predictive models are one dimensional and assume isothermal water at a given depth. This assumption may be violated in impoundments with high flow/ volume ratios (U.S. Army Corps of Engineers 1980). A wide array of stratification patterns may develop in reservoirs, depending on inlet and outlet locations, flows and densities, and the reservoir operating schedule. Wunderlich and Elder (1967) discussed these factors and noted that it is rare for a given stratification pattern to recur in successive years. For complex reservoirs, it may not be possible to precisely characterize an average or "normal" condition.

The U.S. Army Corps of Engineers (1980) and the Tennessee Valley Authority (1976) have developed and tested computer (FORTRAN IV) models for predicting temperatures in stratified lakes and reservoirs. Both models have been tested, and both were judged to perform well. Program listings and instructions are available. Data requirements are considerable, but most of the necessary information is readily available. The TVA model is a modification of that proposed by Ryan and Harleman (1971).

The procedure developed by Burt (1957) for forecasting temperatures in a Snake River reservoir is mathematically less complex than those used by the Corps and TVA, but it, too, is based on an explicit accounting of heat flow. Surface heat exchange is estimated using meteorologic data, and the movement of water and heat through different strata in the reservoir is simulated.

Phosphorus and Nitrogen

Phosphorus concentration does not appear as a variable in any of the early habitat suitability index models developed for this series, but it is of fundamental importance to lake productivity and can be used to predict other water quality parameters. Several models for predicting total phosphorus (TP) concentration in lakes have been developed (Vollenweider 1969, 1975; Imboden 1974; Dillon and Rigler 1975; Snodgrass and O'Melia 1975; Vollenweiden 1975; Larsen and Mercier 1976; Lorenzen et al. 1976; Canfield and Bachmann 1981). These models use a mass balance approach and typically include terms for rate of phosphorus loading (a function of natural drainage basin characteristics, precipitation, and human activity), lake flushing, and loss of phosphorus to the sediments.

Nitrogen (N) also is an important plant nutrient and often limits primary production where phosphorus (P) does not. Lambou et al. (1976) used the ratio of the concentration of nitrogen to that of phosphorus (N:P) to distinquish lakes in which phosphorus is the limiting nutrient from those limited by nitrogen. Lakes with N:P>14 were said to be phosphorus-limited and those with N:P<10 were classified as nitrogen-limited. Lakes with intermediate ratios were characterized as transitional. Nitrogen limitation usually occurs only in highly enriched waters (Wetzel 1975) and, even then, often lasts only for a short time. Long term processes, such as nitrogen fixation, act to correct short term nitrogen deficiencies (Schindler 1977). Nitrogen concentration in lakes is generally an order of magnitude greater than phosphorus concentration, and phosphorus is usually the limiting nutrient (Wetzel 1975). Phosphorus appears to be the limiting nutrient in most midwestern impoundments (Walker and Kuhner 1979). Nitrogen limitation can occur seasonally in epilimnia of lakes for which a lakewide budget would indicate a nitrogen surplus if most of the phosphorus enters in surface runoff and most nitrogen enters the hypolimnion via springs and ground water seepage (Loucks and Watson 1978).

Nutrient models can be used to predict the trophic status of lakes under different conditions. Tapp (1976) reported that the Vollenwider, Dillon, and Larsen/Mercier models all classified 66 southeastern lakes in a way that agreed with National Eutrophication Survey ratings. The Dillon and Larsen/Mercier models performed somewhat better than the Vollenweider model for a set of 39 lakes (Hern et al. 1981). Bradford and O'Maiero (1978) used the Imboden and Dillon models to predict the likelihood of cultural eutrophication in a proposed reservoir. Their study illustrated the applicability of nutrient loading - productivity relationships to water resource planning.

The rate of nutrient loading depends on the climate, size, geology, land use, and population density of the drainage basin (Schindler 1971; Dillon and Kirchner 1975). Bedrock geology and climate generally can be considered as constants when making water quality projections for different years, but changes in human activity in the drainage basin must be considered in order to effectively apply the nutrient models. Several authors have discussed relationships between land use and nutrient loading (Keup 1968; Dillon and Kirchner 1975; Dillon and Rigler 1975; Haith 1976; Loucks and Watson 1978). Concepts reviewed and developed in these papers provide a basis for forecasting water quality conditions in different target years, given projections about future land use patterns. Sylvester (1957) predicted water quality conditions in the Columbia River on the basis of anticipated changes in watershed usage.

Nutrient concentrations in reservoirs during and immediately after initial filling are often higher than would be expected on the basis of nutrient concentrations in inflowing streams. Additional nutrients are released from the decomposition of inundated vegetation and from inundated soils. Nielson (1967) outlined methods for predicting nutrient inputs to proposed reservoirs from these sources. Henderson et al. (1973) noted that 5 to 15 years were usually required before the productive capacities of recently impounded tropical reservoirs stabilized.

Transparency

The concentration of chlorophyll a (chl a), an indicator of algal density, can be predicted from TP concentrations and used to predict Secchi disk transparency (Sakamoto 1966; Dillon and Rigler 1974, 1975; Jones and Bachmann 1976; Canfield and Bachmann 1981; Hern et al. 1981). Correlations between TP and chl a and between chl a and Secchi depth are greater for natural lakes than for impoundments, perhaps because of higher nonalgal turbidities in the latter (Walker and Kuhner 1979; Canfield and Bachmann 1981). High sediment loads limit light penetration and algal growth in some midwestern (Walker and Kuhner 1979) and Great Plains (Hergenrader and Hammer 1973) reservoirs. Hern et al. (1981) also discussed the distortions that high sediment loads may impart to the TP - chl a - Secchi depth relationships.

Dissolved Oxygen

The rate of organic production in the surface layer affects the rate of oxygen depletion in bottom strata. Gilbertson et al. (1972) reported a negative correlation between hypolimnetic oxygen concentration and phosphorus loading rate for Lake Erie. Cornett and Rigler (1979) showed that the rate of oxygen depletion in the hypolimnia of oligotrophic lakes can be predicted as a function of phosphorus retention, average hypolimnetic temperature, and the average thickness of the hypolimnion. Hutchinson (1938) documented a proportional relationship between plankton standing crop and hypolimnetic oxygen deficit in Wisconsin lakes, indicating that transparency might be a useful predictor of bottom dissolved oxygen concentrations. Lasenby (1975) noted a correlation between Secchi depth and areal hypolimnetic oxygen deficit for 14 Ontario lakes and calculated a regression equation relating the two. Such equations should not be applied outside of the region for which they were derived; the relationship should be evaluated and calibrated on a regional basis.

These empirical methods also should be applicable to stratified impoundments with low flushing rates. This includes many storage reservoirs, but excludes most mainstream impoundments. Bottom waters in reservoirs of the latter type do not remain isolated from the surface for nearly as long as do bottom waters in stratified lakes or storage reservoirs (Kittrell 1959). This does not necessarily mean that mainstream reservoirs will be well oxygenated. Kittrell (1959) noted that reaeration may be limited in such reservoirs due to relatively low surface area.

Many of the models for predicting dissolved oxygen concentration in streams were developed as planning tools for wastewater management. They essentially treat the water in a stream or river as diluted sewage (Straskraba 1973) and are patterned after the early work of Streeter and Phelps (1925).

These models contain one term to account for bacterial oxidation of organic matter and another for atmospheric reaeration. More realistic models incorporate the effects of additional processes, such as respiration and photosynthesis by the aquatic biota (Nielson 1967; Grenney et al. 1976; Grenney and Kraszewski 1981).

Basin Configuration

Erosion and sedimentation can dramatically alter reservoir basin configuration in a relatively short period, and the changes may affect habitat suitability for fishes (Il'ina and Gordeyev 1970; Benson 1980). Shoreline modifications are typically most rapid immediately after filling, when the shoreline is irregular and beaches have not formed (Twenhofel 1961, cited in Benson 1980). Shore processes tend to smooth irregular shorelines by eroding headlands and forming sand bars across the mouths of bays. Benson (1980) observed that the development of stable shore configuration and slope in large reservoirs seems to require about 20 to 25 years. Il'ina and Gordeyev (1970) reported that the inshore zone of a reservoir in the Soviet Union underwent extensive modification during the first 27 years of operation and then appeared to stablilize. If water levels fluctuate widely, beach development may be inhibited (Benson 1980).

Sediment is imported to reservoirs from their drainage basins. Reservoirs act as sediment traps and will eventually fill unless preventive or remedial measures are taken. The rate of filling depends on reservoir and drainage basin characteristics, such as size, geology, land use, and precipitation (Paulet et al. 1972).

These physical processes also occur in natural lakes (Wilson 1935), but the radical changes in shoreline have, in most cases, already occurred, and sediment loads are generally lower than they are in reservoirs (Walker and Kuhner 1979; Canfield and Bachmann 1981). However, this depends a great deal on land use in the drainage basin.

Fish habitat evaluations should consider the probable occurrence of an adjustment period after reservoir filling. Unfortunately, general predictive models for shore formation are not available (Benson 1980). Case histories, such as those provided by Benson (1980) for five Missouri River reservoirs are very useful. The U.S. Army Corps of Engineers has supported some work concerning the prediction of sediment loads and sedimentation rates in reservoirs. A bibliography of available documents (U.S. Army Corps of Engineers 1981) can be obtained from the Hydrologic Engineering Center in Davis, California.

Stream Width, Depth, and Velocity

Width, depth, and velocity in streams are dependent on discharge. Computer programs (IFG-1, Water Surface Profile (WSP), and IFG-4) have been developed to predict these parameters as a function of discharge (Milhous et al. 1981). These hydraulic simulation programs require precise measurements of water depths and velocities. Recommended measurement techniques are described in Bovee and Milhous (1978).

Aquatic and Wetland Vegetation

The following publications contain information that may be useful in the prediction of vegetation composition and density. They do not contain predictive models, but do provide information concerning the occurrence of different plant species and vegetation types with respect to environmental variables. Boyd (1971:155) noted that "... where habitat for plant growth occurs, nothing short of removing the habitat will prevent vegetational development". Some of the references are general; others are site or region specific. Brief annotations are included for some of the references. The list is far from exhaustive.

Anderson, R. R., R. G. Brown, and R. D. Rappleye. 1968. Water quality and plant distribution along the upper Patuxent River, Maryland. Chesapeake Sci. 9:145-156.

Deals primarily with the estuarine distribution of emergent and submerged macrophytes, with respect to salinity.

Boyd, C. E. 1971. The limnological role of aquatic macrophytes and their relationship to reservoir management. Pages 153-166 in G. E. Hall (ed.). Reservoir fisheries and limnology. Am. Fish. Soc. Spec. Publ. 8.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S.D.I. Fish Wildl. Serv., Off. Biol. Serv. FWS/OBS-79/31. 103 pp.

Fassett, N. C. 1930. The plants of some northeastern Wisconsin lakes. Trans. Wisc. Acad. Sci., Arts, Lett. 25:157-168.

Golet, F. C., and J. S. Larson. 1974. Classification of freshwater wetlands in the glaciated northeast. U.S. Bur. Sport Fish. Wildl. Washington, DC. Resour. Publ. 116. 56 pp.

Provides a classification scheme and descriptions of environmental conditions under which different wetland types develop. Also includes photographs of examples of wetlands types.

Hoffman, G. R. 1978. Shore vegetation of Lakes Oahe and Sakakawea, mainstem Missouri River reservoirs. Dept. Biol., Univ. South Dakota, Vermillion, SD. 206 pp.

Discusses inundation tolerance of different shoreline plants, effects of cattle grazing, successional patterns, and recommendations for maximizing shore vegetation.

Moyle, J. B. 1945. Some chemical factors influencing the distribution of aquatic plans in Minnesota. Am. Midl. Nat. 34:402-420.

Discusses occurrence of aquatic plants in Minnesota, with respect to total alkalinity, pH, and sulphate ion concentration.

Peltier, W. H., and E. B. Welch. 1969. Factors affecting the growth of rooted aquatics in a river. Weed Sci. 17:412-416.

Descriptive and experimental study of the effects of depth, turbidity, and sediment nutrient concentrations on the growth of plants in a Tennessee river.

______________. 1970. Factors affecting growth of rooted aquatic plants in a reservoir. Weed Sci. 18:7-9.

Discusses role of nutrients, light, and water level in regulating plant growth in an Alabama reservoir.

Penfound, W. T. 1953. Plant communities of Oklahoma lakes. Ecology 34:561-583.

Survey of terrestrial (nearshore), wetland, and aquatic vegetation of lakes and reservoirs throughout the State, with particular reference to climatic factors and lake conditions (water level fluctuations, sedimentation rates, substrate, depth, and alkalinity). Also discusses implications of different water level regimes for vegetational succession.

Penfound, W. T., T. F. Hall, and A. D. Hess. 1945. The spring phenology of plants in and around the reservoirs in north Alabama with particular reference to malaria control. Ecology 26:332-352.

Contains useful information on the relative tolerance of terrestrial, wetland, and aquatic plants to inundation and desiccation.

Rawson, D. S., and J. E. Moore. 1944. The saline lakes of Saskatchewan. Can. J. Res. 22:141-201.

Stewart, R. E., and H. A Kantrud. 1972. Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors. U.S. Geol. Surv. Prof. Pap. 585-D. 36 pp.

Swindale, D. N., and J. T. Curtis. 1957. Phytosociology of the larger submerged plants in Wisconsin lakes. Ecology 38:397-407.

Discusses environmental correlates of macrophyte community structure, especially substrate, depth, and conductivity.

Wilson, L. R. 1935. Lake development and plant succession in Vilas County, Wisconsin. Ecol. Monogr. 5:207-247.

Discusses aquatic plant community structure in terms of lake successional state. Also describes the distribution of different types of vegetation within lakes in relation to environmental factors.

______________. 1939. Rooted aquatic plants and their relation to the limnology of freshwater lakes. Pages 107-122 *in* F. R. Moulton (ed.). Problems of lake biology. Am. Assoc. Adv. Sci. Publ. 10, Science Press.

Zoltai, S. C., F. C. Pollett, J. K. Keglum, and G. D. Adams. 1973. Developing a wetland classification for Canada. Pages 497-511 in Proc. N. Am. Forest Soils Conf., Laval Univ., Quebec, Canada.

RIVERINE AND LACUSTRINE DATA RECORDS

Figures A-4 and A-5 provide a means of recording habitat data and provide a starting point for development of simplified forms for site specific applications.

Riverine Data Record

Pages 1 and 2 of Figure A-4 are used to record data for a single transect site. A tape should be stretched from one side of the bank to the other, at a right angle to the stream channel. Habitat conditions for each appropriate variable are measured directly underneath the tape. In large streams, the tape may have to be attached to a cable for support. When it is not feasible to stretch a tape across a river, a range finder or plane table should be used to determine positions. Page 3 (Fig. A-4) summarizes field data for up to 10 transects. Full size copies of the riverine data record can be obtained by writing to the address listed in the preface of this publication. Instructions for completing each page of the data record are provided below.

Riverine data record: page 1.

Water resource subregion - enter the water resource subregion in which the sample site is located.

Stream - enter the name of the stream.

Sampling area number - enter a code or descriptor to identify the exact area being sampled.

Transect number - assign and enter the number of the transect being evaluated.

Stream width - enter the width of the stream, water edge to water edge, perpendicular to the direction of water flow.

Channel width - enter the distance between normal high water marks.

Date - enter the date (month/day/year) that the survey was completed.

Investigators - enter the name(s) of the person(s) doing the sampling.

Bank for 0 point - check the appropriate boxes to indicate if the 0 point of the tape is on the right bank or the left bank and whether you were looking upstream or downstream when determining right bank and left bank. It is easier to interpret field data if all tape readings have a 0 point on the same bank.

Water resource subregion ______________ Date ___/___/___ Page 1

Stream name ______________ Investigators ______________

Sampling area # ______________ Bank for 0 point: Right ☐ Left ☐

Transect # ______________ Looking upstream ☐

Stream width ______ Channel width ______ Looking downstream ☐

Instream cover						
Tape reading		Undercut bank	Brush, logs, debris piles	Overhanging vegetation	Inundated vegetation	Veg. density code
Start	End					

Pool measurements						
Tape reading		Pool rating			Maximum pool depth	Velocity at ___ from sur.
Start	End	1 (deep)	2 (mod.)	3 (shal-low)		

Riparian area																
Percent of ...										Bank stability						Shade
Trees		Shrubs		Grasses & forbs		Bare				R. bank			L. bank			
						Rock		Dirt								
R	L	R	L	R	L	R	L	R	L	S	M	U	S	M	U	

Figure A-4. Riverine data record.

Water resource subregion____________________ Date__________/__/__ Time of day________

Stream name____________________ Investigators______________________________

Sampling area #____________________ Bank for 0 point: Right ☐ Left ☐

Transect #____________________ Looking upstream c l

Stream width________Channel width________ Looking downstream c l

Tape reading		Substrate type										Velocity				
Start	End	Bedrock	Lg. boulder (> 46 cm) or ( )	Boulder (25-45 cm) or ( )	Rubble (6-25 cm) or ( )	Gravel (6-60 mm) or ( )	Sand (.06-6 mm) or ( )	Mud/silt (< .06 mm) or ( )	% embeddedness	Dry ground		Tape reading	Depth	0.6 below surface	___ below surface	

Water quality

Temperature____________

pH____________

Dissolved O_2____________

Turbidity ____________

Salinity ____________

Alkalinity ____________

TDS ____________

Tape reading ____________

Fluctuation rating: ______

Permanent ____________

Intermittent ____________

Additional comments:

Figure A-4. (continued)

Sampling area location ______________________

Water resource subregion ______________________

Stream name ______________________

Flow conditions ______________________

transects in sample area ______________________

Distance between transects ______________________

Investigators ______________________

Date(s) ______________________

	Physical									Water quality						Other		
Transect number	Stream width	Pool width	Riffle/run width	Average pool rating	Predominant sub-strate class					Salinity	Temperature	pH	Dissolved O_2	Turbidity				

Comments:

Fluctuation rating:

Permanent ________

Intermittent ______

Average annual discharge:

Other:

Figure A-4. (concluded)

Name of lake or reservoir ________________ Latitude ________________

Water resource subregion ________________ Longitude ________________

Elevation (m)	
Surface area (ha)	
Volume (m^3)	
Mean depth (m)	
Maximum depth (m)	
Length of shoreline (km)	
Shoreline development factor	
Storage ratio	
Flushing rate (days)	
Water level fluctuation	

Inlets: ____________________________ Surrounding topography & vegetation:

____

____

Outlets: ____________________________ Remarks: ____________________________

____

____

Figure A-5. Lacustrine data record.

Name of lake or reservoir ______________________ Sampling area ______________________

Date ______________________ Transect number ______________________

s ______________________ Zero point for transect (shore) ______________________

Length of transect ______________________

Cover									Substrate									
Distance		Type							Distance		Type (size, in mm)						Depth	
Start	End	Boulders	Cavities	Brush, debris, logs, timber	Aquatic vegetation	Flooded vegetation		Vegetation density	Start	End	Boulders (> 250) or ( )	Rubble (60-250) or (-)	Gravel (2-60) or (-)	Sand (0.06-2) or (-)	Silt (< 0.06) or (-)	% embeddedness	Distance	Depth

Figure A-5. (continued)

Name of lake or reservoir ____________ Sampling area ____________

Date/time ____________ Transect number ____________

Investigators ____________ Station ____________

Weather: air temp. ____________ Water depth ____________

sky ____________ Secchi depth ____________

wind direct. ________ velocity ________ Comments ____________

water surface ____________

Depth	Water quality measurement							
	Temperature	Dissolved oxygen	pH	Alkalinity	Specific conductance	TDS	Turbidity	
Surface								

Figure A-5. (concluded)

Instream cover - record the starting and ending reading on the tape for each of the classes of cover encountered along the tape. Check the appropriate box for each reading. When more than one class of cover occurs at the same tape point, e.g., a submerged log beneath an area of overhanging vegetation, record the tape readings and check the appropriate box for each class. Suggested definitions of cover classes are given below.

Undercut bank - the lip of the bank overhangs the edge of the water, and there is less than 0.5 m between the water surface and the underside of the bank at a specified flow.

Brush, logs, and debris piles - leaves, stems, branches, logs, and other manmade or natural debris.

Overhanging vegetation - bank vegetation that is within 0.5 m of the water surface.

Inundated vegetation - submerged and emergent aquatic vegetation and/or inundated terrestrial vegetation.

Vegetation density code - estimate the percentage of the area of the water column or bottom occupied by plant materials at the surface, middepth, and bottom from a vertical projection downward along the transect. Use a width of 0.1 m on each side (upstream and downstream) of the transect. For each of the three depths, enter the appropriate letter or number categories for the density class of vegetation observed.

For example, A3c would indicate ≥ 70% surface density, < 30% middepth density, and < 30% bottom density of vegetation.

Percent covered

Surface	Middepth	Bottom
A) ≥ 70%	1) ≥ 70%	a) ≥ 70%
B) 30-70%	2) 30-70%	b) 30-70%
C) > 0 to < 30%	3) > 0 to < 30%	c) > 0 to < 30%
D) 0	4) 0	d) 0

Pool measurements - record beginning and ending tape reading for each pool encountered along the transect. Areas along the transect that are not pools are considered riffles or runs. A pool is defined as an area of the stream with reduced current that is usually deeper than the average stream depth. Check the appropriate pool rating for each pool, based on observations of the entire pool, not just the area on the transect. A rating for a pool will be entered each time it is crossed by a transect. Ratings are as follows:

a) Class 1 pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult fish. More than 30% of the pool bottom is obscured due to depth, surface turbulence, or the presence of structures, e.g., logs, debris, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is $\geq$ 1.5 m in streams $\leq$ 5 m wide or $\geq$ 2 m deep in streams > 5 m wide.

b) Class 2 pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult fish. From 5 to 30% of the bottom is obscured due to surface turbulence, depth, or the presence of structures. Typical second class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

c) Class 3 pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to very few adult fish. Cover, if present, is in the form of shade, surface turbulence, or very limited presence of structures. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. The entire bottom of a third class pool can usually be seen.

Maximum pool depth - enter maximum depth of pool.

Velocity at depth from surface - enter the velocity reading taken at a specified location and depth from the surface of the pool. Record location under tape reading. For example, if the maximum depth is 2 m, then a velocity measured at 0.8 depth would be 1.6 m below the surface. Depth of measurement is determined by model requirements.

Riparian area - record the percentage of the riparian area that would be covered by a vertical projection downward of the canopy closure of the vegetative class (trees, shrubs, and grasses/forbs) and the percentage that is bare ground (rocks and dirt) for each bank. Because of overlap in canopy closure, such as when shrubs occur under trees, the sum of the percentage cover for all of the vegetative classes may exceed 100%.

Methods for estimating canopy closure are given in Hays et al. (1981). It is recommended that a bank area at least 3 m landward from the stream bank be evaluated.

Bank stability - enter one of the following codes:

S - stable, little evidence of new bank sluffing scars ($\leq$ 10%).

M - moderately stable, new bank sluffing scars (> 10% - $\leq$ 30%)

U - unstable, considerable new bank sluffing conditions apparent (> 30%).

Shade - record maximum % of stream surface that is shaded between 1000 and 1400 hours in midsummer at the transect location.

Instructions for completing the riverine data record: page 2.

Water resource subregion, stream, sampling area number, transect number - enter the same information recorded on page I.

Stream width - enter the width of the stream measured from water edge to water edge, perpendicular to the direction of water flow.

Channel width - enter the distance between the normal high water marks.

Date, Time of day, Investigators - enter the appropriate information.

Time of day - enter the time of day the water quality measurements were made.

Bank for 0 point - check the appropriate boxes to indicate if the 0 point of the tape is on the right bank or left bank and whether you were looking upstream or downstream when determining right bank and left bank. It is easier to interpret field data if all tape readings have a 0 point on the same bank.

Tape reading - start and end - record the starting and ending tape readings for each substrate type located along the surface of the bottom below the tape and check the appropriate box.

Substrate type - If substrate types are intermixed, enter the estimated percentage of the surface area of the bottom covered by each type instead of the check described above. Blanks are provided for alternate substrate size class definitions.

% embeddedness - record the percent depth to which boulders, rubble, or gravel are buried in silt or sand.

Dry ground - enter beginning and ending tape reading for areas of the channel without water, and check the appropriate box. If the substrate type in the dry areas is an important consideration to the project, it can also be classified and recorded.

Blank column - enter any additional transect information needed for the HSI model.

Velocity - measure the velocity at each third of the stream width or more often, if necessary, and record the tape reading point and water depth of the measurement. Velocity measurements made at 0.6 depth below the surface will approximate average column velocity (Bovee and Milhous 1978). An additional box is included for optional velocity measurements at other depths. Always measure the average velocity of the thalweg (deepest point).

Blank column - additional depth and tape readings, without velocity measurements, can be entered in order to develop a detailed cross section profile.

Water quality measurements - measure the selected water quality variables. Be sure that the time of day that the measurements were made or sample was collected is recorded. Record tape reading at measurement site if measurements are taken along transects.

Alkalinity - unless otherwise specified, this refers to total alkalinity (HCO_3^-, $CO_3^=$, and OH-) and should be measured as mg $CaCO_3/l$. Detailed analytical procedures are given in American Public Health Association (1971) and Lind (1979).

Total dissolved solids (TDS) - residue after water is evaporated from a filtered sample dried to a constant weight at 180° C. A standard glass fiber filter disk should be used. TDS is usually reported in mg/l or parts per million (ppm). TDS data for major streams are available from the U.S. Geological Survey.

Temperature - temperature readings should be made concurrently with dissolved oxygen readings and at the times and locations specified in the models.

pH - preferably determined with an electronic pH meter. If necessary, a colorimetric method (indicator solutions or litmus paper) can be used. pH values tend to be highest when photosynthetic activity is high.

Dissolved oxygen - usually determined by the Winkler method (American Public Health Association 1971). If a meter is used, it should be calibrated first. Concentrations of oxygen are usually expressed as mg/l, parts per million (ppm), or percent saturation. Minimum dissolved oxygen levels normally occur just prior to sunrise during the summer months or after prolonged ice and snow cover in winter.

Turbidity - can be determined using a commercial turbidimeter or a colorimeter with accompanying table to convert from meter units to turbidity units (Lind 1979). Standard units are Jackson Turbidity Units (JTU) or Nephelometric Turbidity Units (NTU).

Salinity - weight of salts dissolved in 1 kg of water, after all carbonates have been converted to oxides, all bromides and iodides have been replaced by chlorides, and all organic matter has been oxidized. Usually expressed as parts per thousand. See American Public Health Association (1971) for analytical procedures.

Fluctuation rating - record rating (e.g., minor, moderate, or severe), frequency (e.g., annual, seasonal, or frequent), and time of year of maximum fluctuation. Quantitative definition of the ratings should be included. No standard rating system was found during the development of the data record.

Permanent/Intermittent - check appropriate description for transect being sampled.

Instructions for completing the riverine data record: page 3.

Sampling area # - record the identifying information entered on pages 1 and 2 for the transects being summarized.

Water resource subregion - enter water resource subregion from page 1 of the data record.

Stream name - enter stream name.

Flow conditions - record flow conditions (e.g., low, average, or high) during transect sampling. If possible, record actual discharge rather than a qualitative statement.

transects in sample area - enter the total number of transects in the sample area.

Distance between transects - enter the distance between transects.

Investigators - enter name(s) of field investigators.

Date(s) - list range of dates during which transects were measured (i.e., 7-10 July 1981).

Transect number - consecutively list the numbers of the transects sampled in the sample area. Data are summarized for each transect in the remaining columns.

Physical - summarize the physical data for each transect as follows:

Stream width - enter stream width for each transect from page 2 of the data record.

Pool width - total transect distance that crosses pools is determined by subtracting the starting tape readings from the ending tape readings (from page 1) for each pool on the transect and summing these distances.

Riffle/run width - total transect distance in riffles and runs. Record the stream width for each transect minus the pool width.

Average pool rating - multiply the pool rating for each section of pool recorded on the transect by the corresponding pool width, and divide the sum of products by the sum of the pool widths.

Predominant substrate class - enter the substrate class that was the most common for each transect.

Additional blanks - measurements of other model variables needed in order to calculate species HSI's can be entered in the blank columns.

Water quality measurements - enter the water quality data for the transects (from page 2) for each variable measured.

Other - record any other information in these columns that was collected on the transects.

Comments - this section is used to record information, applicable to the entire sample reach, that may help in data interpretation.

Fluctuation rating - enter fluctuation data from page 2.

Permanent/intermittent - enter data from page 2.

Average annual discharge - enter data from discharge records.

Gradient - record the vertical drop in elevation per unit distance.

Other - record any additional data collected but not entered on forms.

Lacustrine Data Record

Instructions for completing the lacustrine data record: page 1. This page contains a listing of geographic, morphometric, and hydrologic variables for lacustrine habitats for which data can usually be obtained without a site visit. These variables are defined below and sources of data included when available.

Name of lake or reservoir - enter name of body of water.

Water resource subregion - enter the number(s) of the water resource subregion(s) in which the water body is located.

Latitude - enter latitude in degrees and minutes.

Longitude - enter longitude in degrees and minutes.

Elevation - outlet or spillway elevation above sea level.

Surface area - surface area of lake (reservoir) at full capacity. Water level elevation for which surface area was calculated should be specified. Other surface areas (e.g., average or minimum) may be listed if identified.

Volume - volume at full capacity.

Mean depth - volume divided by surface area. Mean depth can be estimated from depth measurements taken along transects. Specify water surface elevation at time of data collection.

Maximum depth - maximum depth at full capacity. Use contour maps or transect measurements to determine depth.

Length of shoreline - length of perimeter of water body at specified capacity.

Shoreline development factor - length of the shoreline (L) divided by the length of the circumference of a circle with a surface area (A) equivalent to that of the lake, that is:

$$SDF = \frac{L}{2\sqrt{\pi A}}$$

The ratio is dimensionless and has a minimum value of 1 (circular lake).

Storage ratio - ratio of the volume of the water body to its average annual discharge.

Flushing rate - the number of days required for a volume of water equivalent to the reservoir volume to be discharged. Divide the volume of the reservoir by the daily discharge for the specified time period.

Water level fluctuation - record amount (e.g., minor, moderate, or severe), frequency (annual, seasonal, or frequent), and time of year of maximum fluctuation. Use quantitative fluctuation data whenever possible.

Inlets - identify inflowing streams and rivers.

Outlets - identify outflowing streams and rivers.

Surrounding topography and vegetation - describe relief and vegetation of shoreline area.

Remarks - record any other pertinent data.

Lacustrine data record: page 2.

This page is completed when transects are used to sample lacustrine habitat. Sampling along a transect may be continuous or at discrete points. In either case, the starting (zero) point of the transect from which distance will be measured must be established. Habitat variable data should be recorded in terms of distance from this reference point. Distances can be determined with a rangefinder. A series of highly visible, anchored buoys can be used when sampling a long transect. Distances recorded should coincide with significant changes in values for the parameter of interest, such as cover or substrate. In the case of depth, only points at which the slope of the bottom changes appreciably need be recorded. Intervening depths can be determined by interpolation.

Unless the water is very transparent, direct visual observations from the surface will be limited to shallow water. The simplest way to determine values for deeper areas is to interpolate measurements after sampling a series of discrete points along a transect, using remote sampling gear (for example, a bottom grab, echosounder, or sounding line). The number and spacing of sampling stations will depend on the uniformity of the lake and the degree of resolution required.

Name of lake or reservoir - enter name of water body.

Date - enter date on which sampling occurred.

Investigators - enter name(s) of person(s) doing the sampling.

Sampling area - enter the designated name, number, or letter of the sampling area.

Transect number - enter the number of the transect being evaluated. If more than one page is required to complete the transect, record page number and total number of pages (e.g., page 1 of 3).

Zero point for transect (shore) - specify the point from which distances are being measured (for example, SW shore).

Length of transect - record the total length of the transect.

Cover - record the starting and ending distance for each class of cover encountered along the transect, and check the appropriate box. When two or more classes of cover occur together, list each separately. Density of vegetation can also be recorded (see below). Definitions of cover classes are listed below. Data for an additional user-specified class can be recorded in the blank column.

Boulders - all rocks with the longest axis greater than 250 mm.

Cavities - all cavities beneath rocks, logs, or debris. A minimum cavity size should be defined based on species use of cavities.

Brush, debris, logs, timber - includes natural or manmade debris and all woody or herbaceous materials, such as leaves, stems, branches, and standing timber.

Aquatic vegetation - includes all submerged, emergent, and floating aquatic plants.

Flooded vegetation - inundated terrestrial vegetation.

Vegetation density - using a vertical projection from the transect downward, estimate the percentage of the area of the water column or bottom occupied by plant materials at the surface, middepth, and bottom. Use a width of 0.1 m on each side of the transect. Enter the appropriate letter and number codes from the list below.

Surface	Middepth	Bottom
A) > 70%	1) > 70%	a) > 70%
B) 30-70%	2) 30-70%	b) 30-70%
C) > 0 and < 30%	3) > 0 and < 30%	c) > 0 and < 30%
D) 0	4) 0	d) 0

Substrate - record the starting and ending distance for each substrate type listed, and check the appropriate box. If two or more substrate types are intermixed, enter percentage (by weight) of each type in the appropriate boxes. Blanks are provided for user-specified substrate class sizes.

Percent embeddedness - a measure or estimate of the depth (%) to which boulders, rubble, or gravel are buried in silt or sand.

Depth - record the distance along the transect and the depth at that distance for selected points along the transect. The only depth points that need to be recorded are those where the slope of the bottom changes appreciably.

Lacustrine data record: page 3.

This page is used to record water quality data from littoral and pelagic sampling stations. These sampling stations do not need to be located on the transects to sample cover, substrate, and depth. One water quality station should be located at the deepest part of the lake (reservoir). If more than one distinct basin exists, a station should be established at the deepest part of each basin. One "deepwater" station will often be sufficient to characterize the conditions in the pelagic zone at a given time and for a given basin. Littoral areas are usually more variable and require more stations.

Name of lake or reservoir - enter name of water body being sampled.

Date/time - enter the date and time of day the data are collected.

Investigators - enter name(s) of person(s) doing the sampling.

Weather - enter air temperature, sky conditions (e.g., clear, partly cloudy, or overcast), wind direction and approximate velocity, and condition of water surface (e.g., calm, rippled, or slight chop).

Sampling area - enter the designated name, letter, or number of the sampling area.

Transect number (if applicable) - enter the transect number if the water quality station is located on a transect used for cover, substrate, and depth measurements.

Station - identify and locate the station by name or position (e.g., grid coordinates or distance along a transect).

Water depth - enter depth at sampling station.

Secchi depth - enter Secchi disk transparency, as defined by Wetzel (1975).

Comments - enter any additional information concerning sampling conditions, procedures, or equipment that would be helpful in data interpretation.

Depth - record depth associated with water quality measurement or sample.

Water quality measurement - record water quality value under appropriate column, in row corresponding to depth of measurement or sample. Include units of measurement. If a water sample was taken for later analysis, record the identification code for the sample. Space is provided for more measurements than will normally be made at a given time. Certain water quality parameters may not be relevant to a particular study; columns corresponding to these variables should be ignored. Some parameters may only need to be sampled at one depth. Temperature and dissolved oxygen should be measured at more than one depth. Temperature should be the first parameter measured at a given station. Record temperature measurements for surface, bottom, and intermediate depths at sample points where the temperature or temperature gradient changes. If the temperature profile indicates that the water column is well mixed, measurements at a single point (e.g.. at middepth) for other water quality variables are apt to be sufficient. A blank column is included for additional parameter(s) of interest.

Temperature - temperature readings should be made concurrently with dissolved oxygen readings and at the times and locations specified in the models.

Dissolved oxygen - usually determined by the Winkler method (American Public Health Association 1971). If a meter is used, it should be calibrated first. Concentrations of oxygen are usually expressed as mg/l, parts per million (ppm), or percent saturation. Minimum dissolved oxygen levels normally occur just prior to sunrise during the summer months or after prolonged ice and snow cover in winter. Spatial and temporal distribution of oxygen concentrations are discussed in Wetzel (1975).

pH - preferably determined with an electronic pH meter. If necessary, a colorimetric method (indicator solutions or litmus paper) can be used. pH values tend to be highest when photosynthetic activity is high. Spatial and temporal variation of pH is described by Wetzel (1975).

Alkalinity - unless otherwise specified, total alkalinity (HCO_3^-, $CO_3^=$, OH-) should be measured as mg $CaCO_3/l$. Detailed analytical procedures are given in American Public Health Association (1971) and Lind (1979).

Salinity - weight of salts dissolved in 1 kg of water, after all carbonates have been converted to oxides, all bromides and iodides have been replaced by chlorides, and all organic matter has been oxidized. Usually expressed as parts per thousand. See American Public Health Association (1971) for analytical procedures.

Specific conductance - reciprocal of the specific resistance of a solution as measured between two 1 cm^2 electodes placed 1 cm apart (Wetzel 1975). Usually measured with a conductivity meter and expressed in µmhos/cm. The temperature at which the measurement is made should be recorded.

Total dissolved solids (TDS) - residue after water is evaporated from a filtered sample dried to a constant weight at 180° C. A standard glass fiber filter disk should be used. TDS is usually reported in mg/l or parts per million (ppm). TDS data for many major streams are available from the U.S. Geological Survey.

Turbidity - may be determined using a commercial turbidimeter or a colorimeter with accompanying table to convert data from meter units to turbidity units (Lind 1979). Standard units are Jackson Turbidity Units (JTU) or Nephelometric Turbidity Units (NTU).

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This publication provides general guidelines in the field application of aquatic Habitat Suitability Index (HSI) models and reviews methods for predicting future values for selected model variables. These models are used with the Habitat Evaluation Procedures (HEP).

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